THE PROPERTIES OF CONCRETE CONTAINING COCONUT SHELL AS FINE AGGREGATE

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For my beloved mother, father and family

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ABSTRACT

Green environments or environmentally friendly buildings have become a main focus among researchers. It refers to the concept of reusing waste materials to improve or make new products. Therefore, this study aims to examine the use of fine coconut shell (FCS) as a partial replacement of sand and its low thermal conductivity applications. The first part of the research focused on the characterisation properties of fine coconut shell and sand through sieve analysis, laser diffraction sieve, specific gravity tests, bulk density tests, scanning electron microscopy (SEM) and water absorption test. Next, the mechanical properties of fine coconut shell as a partial replacement of sand in concrete were determined through slump tests, compressive strength tests, flexural strength tests, modulus of elasticity tests, splitting tensile strength tests, water absorption tests and water permeability testing. The second part of the research focused on low thermal conductivity applications of fine coconut shell concrete through the thermal conductivity test (k-value) and thermal resistance (r-value) calculations. After collecting the data, a relationship analysis was conducted to find the optimum percentage of fine coconut shell replacement. Next, from the optimum percentage, a wall panel was constructed to check the temperature that penetrated the house. A validation of temperature data from real monitoring was then conducted using Autodesk Ecotect software. The results showed that FCS was finer (≤ 600 µm) than sand (4.25 mm - 150 µm). In terms of mechanical properties, concrete containing fine coconut shell as a partial replacement of fine aggregate demonstrated better performance than normal concrete. Apart from that, the thermal conductivity values for specimens containing coconut shell were lower compared to normal concrete. 50 % of fine aggregate with fine coconut shell was found to be the optimum replacement percentage as it fulfilled all the requirements set by the British Standard and also that of previous research.

ABSTRAK

Kini, konsep binaan mesra alam telah menjadi tumpuan para penyelidik. Ianya adalah konsep kitar semula sisa buangan untuk menjadi bahan baru. Oleh sebab itu, kajian penggunaan tempurung kelapa halus sebagai bahan gantian separa pasir di dalam konkrit dan aplikasi terhadap pengaliran haba agar ia lebih rendah berbanding konkrit normal telah dijalankan. Bahagian pertama kajian ini memfokuskan kepada penentuan sifat-sifat fizikal tempurung kelapa halus dan pasir yang merangkumi ujian analisis ayakan, ujian analisi serakan lazer, ujian graviti tentu, ujian ketumpatan, imbasan imej morfologi partikel (SEM) dan ujian penyerapan air. Seterusnya perincian sifat-sifat mekanikal tempurung kelapa halus sebagai bahan gantian separa pasir di dalam konkrit melalui ujian runtuhan, ujian kekuatan mampatan, ujian kekuatan lenturan, ujian kekuatan tegangan, ujian modulus keanjalan, ujian serapan air, dan ujian kebolehtelapan air telah dijalankan. Bahagian kedua pula memperlihatkan aplikasinya terhadap pengaliran haba yang lebih rendah di dalam konkrit berbanding konkrit normal yag melibatkan ujian konduksi termal (nilai-k) dan kiraan rintangan (nilai-r). Selepas pengambilan keseluruhan data, analisis hubungan antara data dijalankan untuk mencari nilai pengantian tempurung kelapa halus yang optimum. Selepas nilai gantian optimum ditemui, konkrit dinding panel akan dibina untuk memeriksa keadaan suhu yang menembusi rumah. Setelah itu, ujian validasi dari ujian masa sebenar dijalankan menggunakan perisian *Autodesk Ecotect*. Keputusan mendapati sifat fizikal tempurung kelapa halus adalah lebih halus ($\leq$600 μm) berbanding pasir (4.25 mm - 150 μm). Bagi nilai mekanikal, campuran tempurung kelapa halus menunjukan lebih baik berbanding konkrit normal. Selain itu, nilai konduksi haba juga lebih rendah berbanding dengan konkrit normal. Kesimpulannya, berdasarkan dapatan kajian ini, tempurung kelapa halus mempunyai potensi sebagai bahan gantian separa pasir di dalam konkrit dengan peratusan optimum penggantian pada nilai 50 % dan ia menepati keseluruhan syarat di dalam Piawaian British dan kajian lepas.

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BS	-	British Standard
BS EN	-	British European standard
FCSC	-	Fine coconut shell concrete
FCSWP	-	Fine coconut shell wall panel
SEM	-	Scanning Electron Microscope
UTHM	-	Universiti Tun Hussein Onn Malaysia
cm	-	Centimetre
mm	-	Milimetre
^{o}C	-	Degree celcious

CHAPTER 1

INTRODUCTION

1.1 Background

Energy conservation is required due to the growing population and limited natural energy sources. According to Zhang *et al.* (2004), and Martínez-molina *et al*. (2016), one third of the total energy consumption and 40% of greenhouse gas emissions are associated with buildings around the world. Since most people spend around 90% of their lives living indoors, energy conservation and thermal comfort in buildings have become a controversial and phenomenal topic discussed among researchers (Giuli *et al.* 2012). The energy required for keeping buildings cool and maintaining thermal comfort depends greatly on the thermophysical properties of the construction material. This is related to conductive heat loss through walls, roofs, windows and floors. Conductive heat transfer in solids is a mixture of molecular vibrations and energy transport by free electrons (Incropera & Dewitt 1985). Thermal conductivity (k-value) is a material's property that shows heat conduction capability. The energy consumption of buildings depends on the thermal conductivity values of building materials (Khoukhi *et al.* 2016). It is commonly known that buildings made of concrete and the materials used inside the concrete need to be considered in order to maintain or lower energy consumption to enable a comfortable living environment in a building.

Concrete is one of the most widely used construction materials in the world. It is basically made from a mixture of cement, aggregates and water. In recent years, there has been a growing emphasis on the use of waste materials and by-products in construction materials. It is part of the solution to solve environmental issues and ecological problems. Using waste materials not only reduces the cost of concrete materials, it also helps reduce the heat conductivity of a building. There are many types of waste materials from various sectors in Malaysia that have been used in previous research to improve the properties of concrete. One of the sectors that have been taken seriously to improve the properties of the concrete and solve the environmental issues in Malaysia is the agricultural sector.

The agricultural sector is one of the most important sectors for a developing country like Malaysia. In fact, it is the most important feature that differentiates developing countries from developed countries. This sector is likely to have contributed to the foundation of the Malaysian economy in the post-independence era during which the majority of the population was focused on economic activities based on agriculture and mining. Due to rapid economic growth in recent years, the agricultural sector has been seen as an important sector for both continuous economic growth and improved living standards (Ahamed *et al.* 2011). For over the last four decades, this sector had contributed to the growth and development of the Malaysian economy (Kingdom *et al*. 2015).

However, the agricultural sector has also led to the production of many types of agricultural waste (Hamidian *et al.* 2016). One of the examples of agricultural waste is coconut shells. As per the measurement reported by the Food and Agriculture Organisation of the United Nations, 11,864,344 hectares of land are planted with coconut trees which produce 61,708,358 tonnes of coconut, equivalent to a yield of 5.20 tonnes per hectare (Divyashree *et al.* 2016). Coconut is a natural resource that benefits mankind. Some of the advantages are high specific strength and modulus, low density, renewability, biodegradability and absence of health hazards (Datta & Kopczyńska 2015). The coconut fruit itself contains 3 layers called the exocarp, the mesocarp and the endocarp (Nguyen *et al.* 2016a). Figure 1.1 shows the cross section of a coconut fruit.

The endocarp, also known as the coconut shell, is discarded as waste after being scraped out (Gunasekaran *et al.* 2014). Coconut shells are mainly used as ornaments, household utensils, and a source of active carbon (Castro *et al.* 2012). Apart from the uses mentioned, most of the coconut shells are left to decompose in the fields (Ganiron 2013). Thus, this becomes an environmental issue. Therefore, the usage of coconut shells as a raw material in the industrial sector can help reduce pollution and transform waste into a valuable resource.

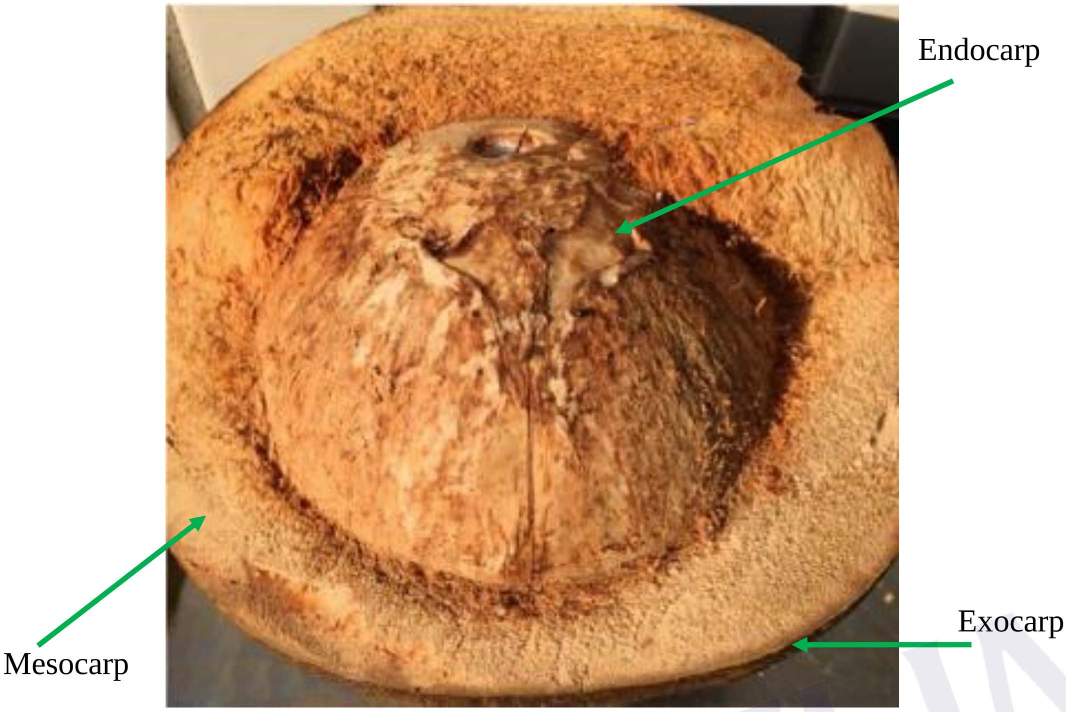

Figure 1.1: The cross section of coconut fruit (Nguyen *et al.* 2016a)

Recently, research on coconut shells has been extensively conducted for specific applications such as concrete materials (Johari *et al.* 2015). By adding coconut shells to concrete, environmental advantages such as less dependence on non-renewable energy or materials, lower pollution and reduced greenhouse emissions can be obtained (Sarki *et al.* 2011). Over the years, many researchers have used coconut shells as a partial or full replacement for coarse aggregates (Basarkar *et al*. 2016). All the properties for coarse aggregate replacement show promising results and it has been claimed to be a suitable material to be used in concrete (Gunasekaran *et al*. 2014).

However, there are limited research studies on the use of coconut shell as a partial replacement of fine aggregate and its use for lowering the temperature of residential buildings. Therefore, this study will mainly focus on fine coconut shell as a fine aggregate replacement. Coconut shells need to be ground into a fine powder so that it is similar or finer in size before it is used as a partial replacement. This is due to the contribution to the small area of the interface between sand and the cement matrix (Xu & Chung 2000). The smaller the interface, the stronger the concrete becomes. Apart from that, the structure of coconut shell itself that has pores and voids makes it suitable for decreasing heat conductivity.

1.2 Problem statement

This subchapter is divided into two phases. The first phase is about thermal comfort and the second phase is about coconut shell which is a type of agricultural waste used as a partial replacement of fine aggregate. The solution for solving both problems is also discussed in this subchapter.

The rapid growth of the housing sector in city areas has become a serious problem as the population increases. Due to this matter, the need for thermal comfort indoors and outdoors, as well as basic amenities and infrastructure, is emphasised. All these things can improve the quality of life of the community especially in city areas (Haryati 2010). As mentioned by Giuli *et al.* (2012), most people spend around 90% of their lives living indoors, hence leading to the need for well-insulated buildings to ensure the occupants live a comfortable life. The easiest way to ensure thermal comfort is to measure the thermal conductivity of houses which mostly come from concrete walls. Lower thermal conductivity will result in low temperature inside the house as thermal conductivity travels in solids from a mixture of molecular vibrations along with energy transported by free electrons. More voids and pores inside concrete walls will lower the temperature inside the house. The voids and pores comes from the material used to construct the concrete wall (Asadi Iman *et. al.* 2018)

A comfortable thermal state defines that the human body is in a comfortable zone and at a minimum level of activity. In this zone, the human body does not need to do any action to maintain heat balance. Many research studies have been done to determine the thermal comfort needed by normal human beings. Studied by Markham (1947) suggested that the ideal room temperature is between 15.6 ^{o}C to 24.5 ^{o}C. However, the ideal temperature is different for each country depending on the climate. For example, according to research done by Bedford (1936), thermal comfort for countries with a cold climate such as the United Kingdom lies between 14.5 ^{o}C and 21.11 ^{o}C. On the other hand, thermal comfort for tropical areas lies between 23.4 ^{o}C and 29.5 ^{o}C while thermal comfort for areas with a dry climate such as Africa and Australia lies between 31.1 ^{o}C and 33.9 ^{o}C. In this thesis, the location for conducting the experimental work is Malaysia. All the values above are for the purpose of comparison between other states and Malaysia itself.

Rahman (2000), stated that thermal comfort for Malaysian climate lies between 25.5 ^{o}C and 28 ^{o}C with optimum comfort at 26 ^{o}C. At this temperature, people living inside a house tend to feel comfortable. Rahman also mentioned that if the temperature change exceeds 2.0 °C from the optimum level, discomfort will be experienced by individuals. Even though the optimum thermal comfort for Malaysia is 26 °C, a research conducted by Shafii (2012), showed that the temperature inside houses in Bandar Baru Bangi, Malaysia, lies in the range of 25 °C to 30 °C for a terrace house whereas the highest range of temperature between 24 °C to 32 °C was observed for an apartment. Although the temperature inside a house can be lowered using air conditioners or electric fans, it can cause an increase in the cost of living.

Furthermore, according to Kardooni *et al.* (2016), as the most visited country in Southeast Asia, the temperature in Malaysia has increased by 0.18 ℃ per decade for over 40 years. From the data received, it is crucial to ensure that the people of Malaysia are able to live in a cool house and have a comfortable thermal surrounding although the temperature has risen. If outdoor temperature increases, the thermal comfort within a house can also be affected as heat can be transferred from an outer surface to an inner surface. Therefore, an optimum thermal comfort of 26 °C cannot be achieved. Hence, a solution is needed in order to lower the indoor temperature of houses and to reduce the cost of living.

One of the solutions that can be taken is to incorporate materials inside concrete that is able to lower the k-value. K-value is defined as thermal conductivity or the ability of material to conduct heat. The higher the k-value the faster material become hot due to the heat transfer and vice versa. The normal k-value for normal concrete used to construct wall panels in construction areas lies between 0.7 to 0.75 W/mK. By lowering the k-value or thermal conductivity value, heat transfer within a building can be reduced. According to Sengul *et al.* (2017) thermal conductivity also depends on the porosity of concrete. Normal concrete consists of cement, coarse aggregate, fine aggregate and water. This combination needs to be modified in order to obtain similar or slightly different basic properties such as strength, water absorption and water permeability but totally different k-values. Researchers such as Zhang *et al.* (2008), used porous aggregates such as expanded clay and shale. However, the k-value gained was still in the range of 0.7 to 0.71 W/mK. It can be concluded that the temperature inside the house decreased by 0.1 °C. Agricultural waste has low thermal conductivity which can lower the overall k-value in concrete. The aim of this study is to lower the temperature by 1 °C or 2 °C in order to achieve better thermal comfort in order for individuals to live comfortably. The aim of 1 °C or 2 °C decreases in this study were based on previous research finding by Zhang *et al.* (2008) and Sengul *et al.* (2017).

Considering all the factors above, this research was conducted with the aim of lowering the k-value of concrete that is used to build concrete walls. Agricultural waste was selected as not many research studies have been used as a replacement or as an admixture inside concrete. The selection of agricultural waste was discussed in the second phase of the problem statement.

The second phase of the problem statement consists of the selection and type of agricultural waste that is used in this study. The selection and type of agricultural waste were based on the total waste produced in Malaysia as explained below:

Concrete is widely used in building construction. Concrete is a mixture of cement, coarse aggregates, fine aggregates and water (Sabih *et al.* 2016). Fine aggregates make up approximately a quarter of the total volume of the concrete matrix (Tiwari *et al.* 2016). Normally, fine aggregates are defined as natural sand collected from rivers or mines. The chemical composition of fine aggregate differs according to local rock sources and conditions. The reliance on these sources for rapid development and housing for construction purposes in Malaysia has further led to a high demand for these raw materials. Due to this matter, natural sources are decreasing day by day.

Recycling waste materials is therefore highly recommended in order to promote a greener and healthier earth. The usage of agricultural waste is emphasised in this research. Properties such as renewability, low-cost, lightweight, high specific strength and stiffness are ideal for construction material selection (Zhao *et al.* 2015). Coconut shell, oil palm shell, oil palm clinker, corncob ash and rice husk ash are agricultural byproducts. Although some of these materials can be used as animal food or fuel in biomass power plants or boilers of various industrial sectors to produce steam, a lot of these materials are still disposed off in landfills or burnt, thereby causing environmental problems (Rashad 2016). By reusing the agricultural waste, this study were complying with the Sustainable Development Goals or SDG under goals number 9 for industries, innovation and infrastructure that stated by 2030, it is aimed to upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally technologies and industrial processes, with all countries taking action in accordance with their respective capabilities. SDG 9 also aims to doubling the manufacturing industry and investment in scientific research and innovation.

Coconut shells are considered as waste that pollute the environment. However,

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